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RELATION H/T IN STRUCTURES OF BAHÍA DE CARAQUEZ AND THE 2016 EARTHQUAKE

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ABSTRACT

A way to evalue the vulnerability of the structures is through of the relation height of the structure H with relation to the fundamental period of vibration T. Now well this period can be obtained in analytical form or like in the present case, implementing the building.

In this article appears the period of vibration that there had 13 buildings of reinforced concrete, located in the Bahía de Caráquez city, the same ones who supported the April 16, 2016 earthquake, which had a magnitude at the moment of 7.8. In such a way that the periods found instrumentally correspond to structures that penetrated into the not linear range.

With the relation H/T found in 13 structures, there is analyzed the degree of hurt(damage) that they had during the earthquake, in order that in a future this relation is born in mind in the seismic design of the structures.

RELACIÓN H/T EN ESTRUCTURAS DE BAHÍA DE CARÁQUEZ Y EL TERREMOTO DE 2016

RESUMEN

Una forma de evaluar la vulnerabilidad de las estructuras es mediante la relación altura de la estructura H con relación al período fundamental de vibración T. Ahora bien este período se puede obtener en forma analítica o como en el presente caso, instrumentando el edificio.

En este artículo se presenta el período de vibración que tuvieron 13 edificios de hormigón armado, ubicados en la ciudad de Bahía de Caráquez, los mismos que soportaron el terremoto del 16 de abril de 2016, que tuvo una magnitud de momento de 7.8. De tal manera que los períodos hallados instrumentalmente corresponden a estructuras que incursionaron en el rango no lineal.

Con la relación H/T encontrada en las 13 estructuras, se analiza el grado de daño que tuvieron durante el terremoto, para que en un futuro se tenga en cuenta esta relación en el diseño sísmico de las estructuras.

1. INTRODUCTION

Why there is important the calculation of the seismic vulnerability of structures?

It is important in order that before an earthquake to take corrective actions (reinforcement of structures) with the aim of not have so many losses and the fundamental thing save lives. Accordingly this thematic has been very developed worldwide like can sees below in summarized form.

Several methods exist to evaluate the seismic vulnerability of a structure in rapid way (it is relative because if it demands certain time of calculation) and later there appear four of them: i) The Method of the Coefficient of displacement recommended by FEMA 356; with this method basically the lateral displacement is obtained in the ceiling of a building using a series of coefficients; ii) The Hazus's Method (1999,2003) developed in the United States, in which there is applied the method of the Spectrum of Capacity; Complicated of this method is to find the Spectrum of Capacity of the Structure and this is provided by HAZUS for some structural tipologies, the same ones that have been obtained by means of a statistical treatment of structures built in the United States; iii) The RiskUE Methodology that was developed in Europe following HAZUS's school but adapting to the structures that are building in Europe; to quote some kind castles of stone that is not had in States United (Milutinovic and Tredafinlski,2003; Giovinazzi,2005). The form of calculation is the same of HAZUS; iv) The Italian Methodology that determines an Index of seismic Vulnerability I_V considering several parameters and giving weight to the same ones in terms of the experts' opinion that they promulgated the Methodology on the basis of the lessons learned from earthquakes.

So much with HAZUS's Methodology like RiskUE performance levels are obtained for the structural, not structural elements and its components; the performance levels are: Without damage, Slight, Moderate, Extensive and Complete. Giovinazzi and Lagomarcino (2002).

In these conditions another alternative of calculation exists and it is to find the relation H/T that is the one that is in use in this study. Being H the total height of the building and T the period of fundamental vibration. This parameter was proposed initially by Guendelman, (2000); Guendelman *et al.* (2012) which analyze structures from 1 to 45 floors constructed in Chile. Later, Massone et al. (2012) and Lagos et al. (2012) find this relation for buildings of Chile constructed between 1940 and 2010. With similar conclusions to the offers for Guendelman, (2000)for Guendelman et al. (2012).

The results of Guendelman *et al*. (2012) establish that the structures with H/T value among 20 and 40 are flexible structures; the normal thing is that the relation H/T find

it between 40 and 70. Lower values than 20 correspond to extremely flexible structures and values superior to 70 rigid structures.

But this working with the period of vibration found analytical considering thick inertias in its elements (without damage).

In the figure 1, appears the períodos of vibration and the total height of the structures analyzed by Guendelman *et al.* (2012) in Chile, are indicated also with blue the four ranges that they used for the classification of the vulnerability of the Structures. In this figure has added the offer of Rodríguez (2018) with red lines, the one who names T_0 to the period of vibration founded analytically; the offer is that if the structure has values of $\frac{H}{T_0} \leq 30$ the structure is flexible and if the values of $\frac{H}{T_0} \geq 75$ the structure is rigid.

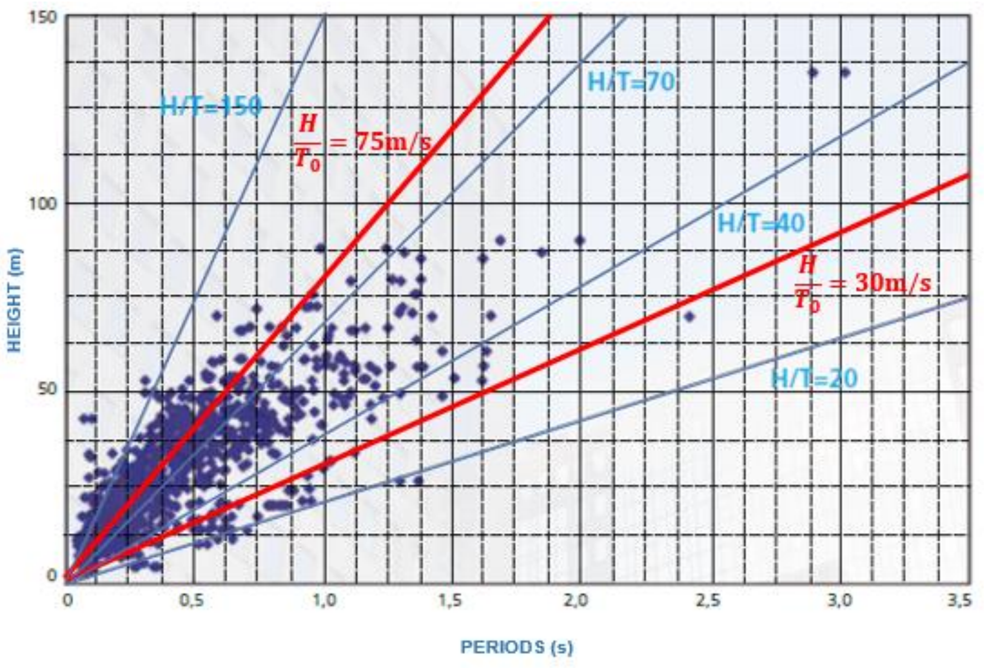
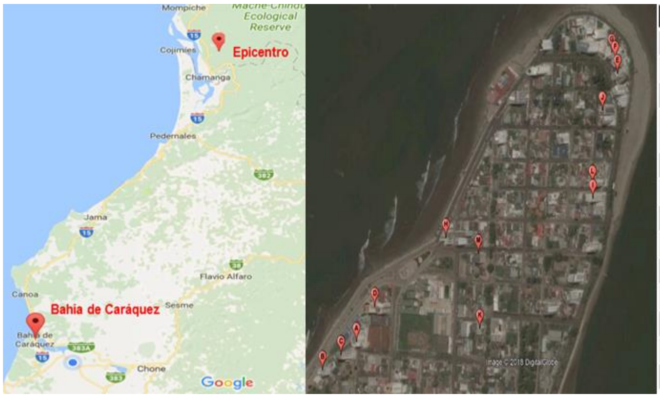


Figure 1 Values of height of floors and periods met analytical thick inertias, of structures from Chile. **Source:** Guendelman *et to*. (2012)

In this article presents this relation H/T but in structures that had some degree of affectation during the earthquake of 16 A located in Bahía de Caráquez, (see figure 2 a); for the effect measured up the period of vibration in the structures post earthquake. The analyzed structures, they are all of reinforced concrete, its location appear in the figure 2 (b) and 2 (c), where also the number of floors is indicated.



LETTER	BUILDING	# FLOORS
A	EL VIGIA	10
B	LAS BRISAS	10
C	HORIZONTE	10
D	2 HEMISFERIOS	9
E	DELFIN	6
F	ALMIRANTE	9
G	MYKONOS	10
H	PIRATA	7
I	SALANGO	10
J	SPONDYLUS	9
K	CEVALLOS	5
L	FRAGATAS	10
M	ZEDEÑO	7

(a) **(b)** **(c)**

Figure 2 (a) Location of the Epicentre of the earthquake of April 16, 2016 and of the Bahía de Caráquez city; (b) Location of the buildings in those who were obtained the period of vibration; (c) Identification of the buildings and number of floors.

2. CALCULATION OF THE VIBRATION'S PERIOD

There are two ways of calculating the vibration's period of a structure; the first one is in analytical way, for the effect determinate the counterfoils of inflexibility and of masses; the second one is in experimental way, for it there are three kind of experimental tests that can determine the dynamic characteristics of the structure in real scale. These are: Vibrations of the traffic of vehicles, of the wind thrust and of the use of the structure, named test of environmental vibration (TEV). Another methodology are the tests of vibration forced (TVF), in which the structure is excited by a constant vibration by one or more engines of vibration that have a precise control of speed. Another method, named test with seismic records (TSR), consists of registering by means of accelerograph the movements provoked by the earthquakes.

For the determination of the vibration's period of the structure it is suitable that the equipments take place in far away areas in order that the records do not meet affected by the persons' step, since any movement of the seismographs with regard to the building alters both the energetic content and the spectrum of frequencies of the sign, and therefore can cause the distortion in the results that are obtained.

With the equipment there is obtained information of longitudinal, transversal and vertical acceleration of the structure, both of the terrace and of the interior of each one of the floors, then Fourier's spectrum is calculated and the fundamental period is obtained in both principal directions.

With Fourier's spectrum of the measured acceleration there is identified the fundamental period of the building and that of maximum extent of minor frequency that is situated inside the interval of frequencies of the structure.

3. ANALYZED STRUCTURES AND VALUES OF H/T

In the table 1, there appear the values of the periods obtained of the buildings indicated in the paragraph 1, the same ones that change between 0.99 and 2.27 for structures from 6 to 10 floors. It is important to emphasize that the study was contracted by the Department of Urban Development and Housing (Ministerio de Desarrollo Urbano y Vivienda) MIDUVI to the Consultant Sanchez (2016) in order that he emits a report on the degree of seismic vulnerability of the buildings.

Table 1. Structures and periods' vibrations founded. Source: Sanchez (2016)

Building	**# Floors**	**H** (m)	**T_{LONG}**	**T_{TRAN}**	**Longitudinal direction** H / T_{LONG}	**Transversal direction** H / T_{TRAN}
Vigía	10	30	1.14 (*)	1.165 (*)	26.31	25.75
Las Brisas	10	35	1.08 (*)	1.20 (*)	32.40	29.17
Horizonte	10	28	1.012 (*)	1.662 (*)	27.67	16.85
Dos Hemisferios	9	27	2.03 (*)	2.27 (*)	13.30	11.89
Delfin	6	25.50	1.15 (*)	1.29 (*)	22.17	19.77
Almirante	9	28	1.22 (*)	1.49 (*)	22.95	18.79
Mykonos	10	32	1.53 (*)	1.78 (*)	20.92	17.98
Pirata	7	28	0.99 (*)	1.60 (*)	28.28	17.50
Salango	10	31	1.25 (*)	1.43 (*)	24.80	21.68
Spondylus	9	26	1.24 (*)	1.61 (*)	20.97	16.15
Cevallos	5	14	1.45 (*)	1.55 (*)	9.66	9.03
Fragatas	10	32	1.12 (*)	1.12 (*)	28.57	28.57
Zedeño	7	18	1.87 (*)	1.966 (*)	9.63	9.16

4. PERFORMANCE OF THE STRUCTURES

The aim of this paragraph is correlating the relation H/T with the performance that the structures had during the earthquake of 16 A. To achieve this aim first of all presents some representative photographies of the seismic behavior of the building and is indicated the relation H/T.

A good part of the analyzed buildings had (some of them were demolished) or they have a swimming pool in the first high floor and the damage centered in the columns of this floor. It is spoken in the past because they have already been overthrown, post earthquake.

- **The Vigia Building**

a) **b)** **c)**

Figure 3. (a) The Vigia Building of 10 floors of HA; **(b)** Lost of covering in parking's column, strong corrosion in the rods of reinforcement; **(c)** High corrosion index in girders of elevator, stirrup without confinement.

The Watchtower building has a relation of average H/T of 26 is observed that there was moderated damage in structural elements in spite of the fact that a high corrosion index exists in the armor.

- **The Brisas Building**

a) **b)** **c)** **d)**

Figure 4. (a) The Brisas Building of 10 floors of reinforced concrete; **(b)** Lost of covering in some structural elements; **(c)** High corrosion index in girders; **(d)** Damages in masonry.

The Brisas building has a relation of average H/T of 30.80 is observed that there was corrosion in the steel of reinforcement so much of girders and columns in subsoil. Great damage in not structural elements.

- **The Horizonte Building**

a) **b)** **c)** **d)**

Figure 5. (a) The Horizonte Building of 10 floors of reinforced concrete; **(b)** The wall of containment presents a vertical fissure; **(c)** The perimetrales flounces suffered accession and product of this observes bulge in the door of access to the area of swimming pool; **(d)** Minor damages in internal masonry and broken windows.

The Horizonte building has a relation of average H/T of 22.25 are observed such damages as slight accession in perimetrales flounces, slight damages in masonry.

- **Two Hemisferios Building**

a) **b)** **c)** **d)**

Figure 6. (a) Two Hemisferios building of 9 floors of reinforced concrete; **(b)** Detachment of covering in front; **(c)** Extensive damage in columns of social area; **(d)** Severe damages in interior and slight masonry in exterior masonry.

The Two Hemisferios building has a relation of average H/T of 12.60 structural damages are observed in the columns and in girders of some floors; to more of that it had damage in not structural elements.

- **The Delfín Building**

a) **b)** **c)**

Figure 7. (a) The Delfín Building of 6 floors of reinforced concrete; **(b)** Detachment of covering in facade; **(c)** Severe damage in internal masonry.

The building Delfín has a relation of average H/T of 21.0 the damages that observed are severe in internal masonry, detachment of covering in facade, besides fissures in slab for cutting fault. Building was demolished post earthquake.

- **The Almirante Building**

a) **b)** **c)** **d)**

Figure 8. (a) The Almirante Building of 9 floors of reinforced concrete located in Bahía de Caráquez city; **(b)** Detachment of covering and fissures in front; **c).** Steel of reinforcement corroded in girder of social area; **d).** Detachment of internal masonry.

The Almirante building has a relation of average H/T of 20.90 the damages that are observed are severe in internal masonry, detachment of covering in facade, and damage in some of the columns of the social area and of the parking, in addition the reinforcement presents corrosion.

- **The Mykonos Building**

a) b) c) d) e)

Figure 9. (a) The Mykonos Building of 10 floors of reinforced concrete; **(b)** Detachment of the covering of the column to the high of the whole floor.; **(c)** Failure of a vain of slab, close to nerve of the same (rotated photography); **(d)** Furniture store of concrete **(e)** Longitudinal fissure close to girder band.

The Mykonos building has a relation of average H/T of 19.45; the building presents strong damages in masonry and in some structural elements.

- **The Pirata Building**

a) b) c)

Figure 10. (a) The Pirata building of 7 floors of reinforced concrete; **(b)** Cracking in masonry; **(c)** Detachment of covering in frontal and posterior facade.

The building Pirata has a relation of average H/T of 22.90; though it had cracking in masonry these did not collapse.

- **The Salango Building**

a) **b)** **c)** **d)**

Figure 11. (a) The Salango building of 10 floors of reinforced concrete; **(b)** Failure for punching and longitudinal fissure in tile low close to the nerve; **(c)** Corrosion in structural elements of slab of cistern and slab of parkings; **(d)** Low tile in ground floor with corroded steel and without adherence.

The Salango building has a relation of average H/T of 23.25; it presents damages in masonry in some cases collapsed; is observed in addition steel of reinforcement corroded in girder that supports cistern.

- **The Spondylus Building**

a) **b)** **c)** **d)**

Figure 12. (a) The Spondylus Building of 9 floors of reinforced concrete; **(b)** Building's facade, major damage of masonry is not observed.; **(c)** Collapsed masonry supported by an electrical duct; **(d)** Cracking in relieved slab on facade window.

The Spondylus building has a relation of average H/T of 18.60; the damages are observed in masonry and detachment of covering in front, fissure in slab and masonry without vertical reinforcement not horizontally.

- **The Cevallos Building**

a) **b)** **c)** **d)**

Figure 13. (a) The Cevallos building of 5 floors of reinforced concrete. **(b)** The formation of kneecaps repeats itself in 7 columns of ground floor in the facade posterior of the building; **(c)** Cracking of masonry they change according to the level of floor; **(d)** Demolished structure.

The Cevallos building has a relation of average H/T of 9.35; were observed damages and presence of plastic kneecaps in 8 columns. Poor detail in stirrups of confinement.

- **The Fragata Building**

a) **b)** **c)** **d)**

Figure 14. (a) The Fragatas Building of 10 floors of reinforced. **(b)** Detachment of covering in frontal and lateral facade; **(c)** Failure for butcher close to the right support of the girder; **(d)** Damage in girders and slab for butcher's effect.

The Fragatas building has a relation of average H/T of 28.60; damage in masonry. The photographies of the figures 14 (c) and (d) correspond to a short girder that penetrated into the not linear range into several floors. This building had damage in the columns of the social area, where the swimming pool was situated. It had a behavior of agreement to the philosophy of design and it was possible to reinforce (Aguiar, 2017) but it was demolished.

- **The Zedeño Building**

a) **b)** **c)** **d)**

Figure 15. The Building Zedeño; **(a)** After The earthquake; **(b)** Damage in columns; **(c)** Crackings in panel of slab; **(d)** Collapse in masonry.

The building Zedeño has a relation of average H/T of 9.40; it presents damage in the top part of some columns of the ground floor, in slab, partial collapse of masonry. It is important bear in mind that the floors 3, 4 and 6 were not finished of repairing, after the affectation that had the building in the earthquake of 1998. In that way they had less weight during the earthquake of 16 A, which helped it in its behavior.

Figure 16 shows the values of the height of the buildings H and the experimentally found period, after the earthquake of April 16, 2016, it is seen that most of the points are at the bottom of the curve $\frac{H}{T} \leq 30$, which corresponds to flexible structures.

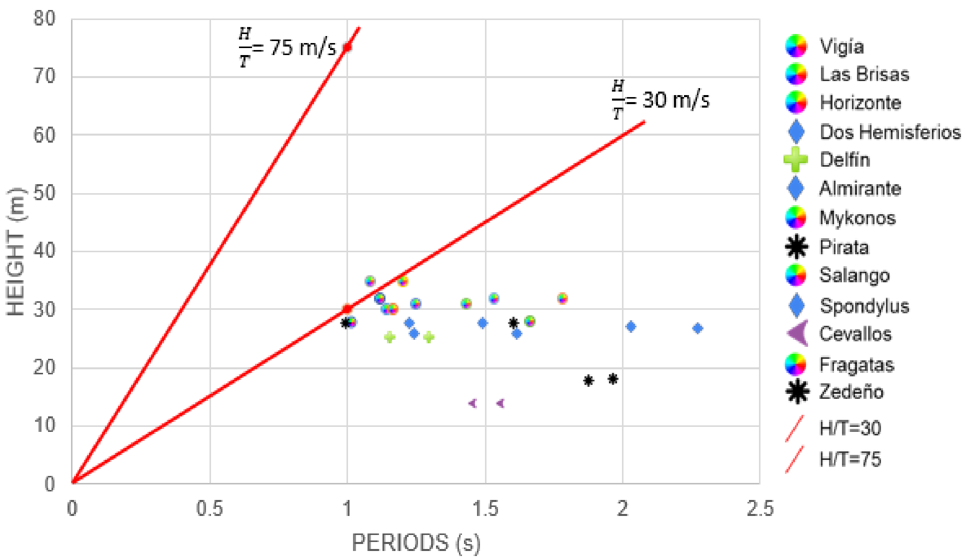


Figure 16 Relationship H / T found in buildings of Bahía de Caráquez, earthquake post 16 A. Source: This study.

5. CURRENT SITUATION OF ANALYZED BUILDINGS

Of the thirteen (13) analyzed structures, twelve (12) of them supported the Bahía de Caráquez earthquake of 1998, which had a magnitude of 7.2; some of these structures were reinforced and others not.

Table 2 Relation H/T and Current State of analyzed Buildings

Building	**Longitudinal direction** H / T_{LONG}	**Transversal direction** H / T_{TRAN}	**State**
Vigía	26.31	25.75	In repair
Las Brisas	32.40	29.17	In repair
Horizonte	27.67	16.85	In repair
Dos Hemisferios	13.30	11.89	In repair
Delfin	22.17	19.77	Demolished
Almirante	22.95	18.79	Demolished
Mykonos	20.92	17.98	Repaired
Pirata	28.28	17.50	Repaired
Salango	24.80	21.68	Demolished
Spondylus	20.97	16.15	In study
Cevallos	9.66	9.03	Demolished
Fragatas	28.57	28.57	Demolished
Zedeño	9.63	9.16	For sale

In the table 2, appears the H / T ratio found with the measurement of the vibration periods obtained in the buildings, after the earthquake of 16 A, and the current condition of the same ones. Can apreciate that the structure with very low values of the relation H/T have not been demolished, since it is the case of the Building Zedeño (9.63 and 9.16) and structures with high values of H/T have been demolished, Frigate building's case (28.57). Therefore, one gave the building overthrow with the assent of its owners.

6. COMMENTS AND CONCLUSIONS

It has presented the values of the periods of vibration found in thirteen (13) buildings of the Bahía de Caráquez city, which were affected by the earthquake of April 16, 2016 (16 A), that had a magnitude of 7.8, with these values obtained the relation H/T.

On the other hand, there has been described in rapid form the behavior that they had during the earthquake of 16 A to be able to correlate the relation H/T with the structural performance. With the realized study have:

That structures with relation minor H/T to 10, resisted the earthquake of 16 A, and later one of them has been demolished.

Structures with relation $10 < \frac{H}{T} < 33$, they presented considerable damage in the masonry and structural damage between moderate and extensively, reason by

which there was done a study of seismic vulnerability tending to obtain a report that indicates if the building must be demolished or reinforced. Those who have been demolished is because consists in the report like that and it was accepted by its owners.

Therefore when the period is obtained experimentally, post earthquake, values of $\frac{H}{T} < 33$ have structural damage and considerable not structural damage.

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